Coordinated Ramping Product & Regulation Procurement in CAISO Using Probabilistic Solar Power Forecasts

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Overview

CAISO & MISO Consultation / Assessment

Thrust 4

Results

Data, System Descriptions, Assessments

Net Load Ramp Uncertainty, ACE

Thrust 2

Ramp Product, Regulation Requirements

System Simulation

Thrust 4

Cost Savings & Reliability Improvements

RAVIS Visualization

Thrust 3

Ramp Alerts & Flexibility Needs

Watt-Sun

Thrust 1

Probabilistic Solar Forecasts

Data, System Descriptions, Assessments

This presentation may have proprietary information and is protected from public release.
Outline

1. Comparison of Watt-Sun to base method: P-P index
2. Using solar forecasting prediction intervals to predict ramp & regulation: the Pareto method
3. Simulation of cost-reliability effects of solar-conditioned ramp requirements on CAISO system
4. Visualization: Resource Forecast and Ramp Visualization for Situational Awareness (RAVIS)
Probabilistic Watt-Sun Flowchart (IBM)

Numerical Weather Prediction Models

Random Forest model to predict solar production

Gaussian Mixture Model & predicted forecast error to predict weather categories

- Quantile regression for each weather category for probabilistic forecast
- Quantile regression for each weather category for probabilistic forecast
- Quantile regression for each weather category for probabilistic forecast
Used quantile regression to deploy probabilistic forecast models

- Quantiles of solar as function of independent variables
- Example results for 2 hr-ahead forecasts

![Graphs showing solar irradiance for April 7, 2020 (Cloudy) and April 20, 2020 (Sunny)]
Evaluation of Watt-Sun

Assessment: Relative Improvement of the PP-Plot Metric

Temporal
- Train: Sept. 1\textsuperscript{st}, ‘18 - Feb. 29\textsuperscript{th}, ‘20
- Test: Mar. 1\textsuperscript{st}, ‘20 - June 1\textsuperscript{st}, ‘20

Spatial
- 24 stations

Map: 24 reference stations
Calibration Quality of Watt-Sun vs. Persistence

Assessment: Relative Improvement of the PP-Plot Metric

A. Baseline: PP-Plot
B. Watt-Sun: PP-Plot
C. Relative PP-Plot Metric Improvement of Watt-Sun

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Assessment: Relative Improvement of the PP-Plot Metric

- Day 1
- Day 5
- Day 92

1st run: 1
1st run: 5
kth run: 2

Rel. Improvement

Time

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Longest Run per Station with Metric Improvement > 20%
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Flexible Ramping Product: CAISO, MISO, SPP

• CAISO: need to forecast three components in real-time:
  • Expected 5 minute ramp forecast
  • Uncertainty in up direction (97.5\textsuperscript{th} percentile)
  • Uncertainty in down direction (2.5\textsuperscript{th} percentile)

• Uncertainty distributions are presently unconditional
  • CAISO revising to condition requirements on wind, load, solar forecasts
    (www.caiso.com/StakeholderProcesses/Flexible-ramping-product-refinements)
Quantile Analysis: Continuous classifier shows potential to adjust net load ramp “up uncertainty” (JHU)

Two Way Classification Results
11 a.m.-2 p.m. May 2019:
97.5% Cutoff (Ramp Requirement) for Each Day Type

Upward Error Quantile Regression Results
11 a.m.-2 p.m. May 2019 (dashed blue lines are, from top to bottom respectively: 90th, 75th, 50th, 25th estimated percentiles)
Out-of-Sample Pareto Analysis of Requirements

Methods:

• Compare performance of MW requirement method relative to ISO baseline method using multiple criteria

• Criteria:
  1. Reliability: fraction of intervals in which MW need exceeds requirement ("shortage")
  2. Cost: total MW-hour / $ cost of requirement

• Assessment procedure:
  • Simulate rolling estimation method (out-of-sample test)
    – Baseline: histograms of N previous days’ realizations of MW need in that interval
    – Alternative: statistical or ML-based estimate of MW need
  • All methods: rescale amount or vary target reliability
    – Tradeoff: more requirements → less shortage but more cost
kNN/PCA-based Method for Flexible Ramp Requirements (UTD)

  - 1-D classifiers from solar site 2 using various predictors
- Multisite/PCA classifiers perform even better

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Out-of-Sample Pareto Analysis of Weather-Aware Regulation Requirements Using Solar Forecasts (JHU)

Quantile Regression-based regulation requirements: Tradeoffs between reliability (fraction of 1-min average adjusted ACE > requirement) & MW supply. (Unconditional and 1- & 3-variable rolling regressions)

Preliminary results:
- ISO baseline method performs well
- Adding forecast variables sometimes improves
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Benefits Assessment using Simulations (NREL)

FRP Analysis March 9-15: Baseline vs. New Flexible Ramp Requirements

- Improvement in reliability
- Expected reduction in generation scarcity and price spike!
- Reduction in renewable curtailment
- Decrease in peaker units scheduling
- Reduction in production costs
Simulation Results – CAISO-like IEEE 118-bus System

- FESTIV market clearing process modified with CAISO operating rules

**IEEE 118 simulated for 3-weeks in March (9-29 2020):**

<table>
<thead>
<tr>
<th></th>
<th>Baseline (Scenario 1)</th>
<th>New FRP (Scenario 2)</th>
<th>Perfect NO uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Production Cost [$M]</td>
<td>23.45</td>
<td>23.05</td>
<td>23.00</td>
</tr>
<tr>
<td>(1.7% savings)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Uncertainty Cost [$M]</td>
<td>0.45</td>
<td>0.05</td>
<td>0.05 (~90% savings)</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

- Uncertainty induced costs reduced by a daily average of 44%
  - Savings in production cost from lower FRP (reduction in peaker units)
  - Higher FRP reduces generation scarcity events and real-time price spikes
  - More flexible generation, with lower min. gen → Reduced curtailment

<table>
<thead>
<tr>
<th>Total VG Curtailment [GWh]</th>
<th>69.1</th>
<th>63.9 (more VG)</th>
</tr>
</thead>
</table>
Results – Large 1820-node WECC / CAISO system

~1,820 buses: 1782 buses for CAISO and 38 for other WECC regions and trading hubs

Copper plate analysis

~$0.27M (1.7%) savings in uncertainty induced costs in 21 days

• $0.27M savings in 21 days ~ extrapolate to $4.7M/yr

• ~ $19.5K (12.7%) savings in FRP procurement costs ~ 340K/yr FRP cost savings
  FRP clearing amount * FRP market clearing price (duals)

With full network

~$0.5M (~3.8%) savings in uncertainty induced costs in 21 days

• $0.5M savings in 21 days ~ Extrapolate to ~$9M/yr, comparable to annual FRP costs

• Further simulation results forthcoming from HPC
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Open-source link to code: https://github.com/ravis-nrel/ravis
**RAVIS: a modular dashboard for viewing:**

- forecast timeline
- spatially relevant forecasts & events
- details of specific events as desired, including market data

**Design:** RAVIS’s technology suite is assembled to provide optimum visualization facility

- Takes advantage of web application technologies and tooling
- These technologies enable deployment in any environment, using any operating system
Can also show net-load time series forecasts and available generation headroom/flexibility

Flexible architecture to visualize more data:
- Net-load forecasts, or each component,
- Available generation flexibility,
- Network nodes,
- Transmission,
- Prices

Sorted ramp events: “most active” (e.g., most events in the next 5 hours)
Summary of features visualized in RAVIS

1) **Site-specific probabilistic solar power forecasts:**
   Hovering reveals forecast data and other meta data; ramp size and direction are shown by circle and arrow.

2) **Time series forecast data:** Clicking a site/region shows individual site-specific probabilistic forecast time series.

3) **Event alerts (e.g., ramp alerts),** at site as well as regional level.

4) **User can configure visualization parameters**
   a) Specific sites or user-defined aggregate regions
   b) Ramp definition customizable by end user.

5) **Data from market clearing engine integrated with forecasts viewer**
   a) **On map:** Network topology, nodal prices, transmission congestion
   b) **On time series:** Available generation flexibility, plotted against net-load forecasts.
Open Source Publicly Accessible / Extensions

Extendable:

- Transmission & Distribution grids with Grid-edge visibility
- **Ongoing project:** Sensor data and cyber threats integration
  - (DOE CESER-funded project Situational Awareness and Grid Analytics (SAGA) project at NREL)

1) Open-source link to code: [https://github.com/ravis-nrel/ravis](https://github.com/ravis-nrel/ravis)

2) Documentation published@ [https://www.nrel.gov/docs/fy21osti/79746.pdf](https://www.nrel.gov/docs/fy21osti/79746.pdf).

Conclusion

- We conclude that probabilistic forecasts are a highly promising way to condition A/S requirements on up-to-date weather forecasts.
- Future: convolve wind, retail load, and solar forecasts for fuller picture.

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Questions?
Backup Slides
9.1A Continuous Improvements of Watt-Sun

Longest Run per Station with a relative PP-Plot Metric Improvement above 20% / 30% (24h Horizon; March 1st, 2020 - June 1st 2020; i.e. 92 days)

- 30%
- 20%
kNN-based FRP requirements: Reliability-oversupply, tradeoffs Feb. 2020. (1-D classifiers from solar site 2 using various predictors)

PCA-based kNN analysis of FRP requirements from multiple sites